Analysis of Population Trends in Warblers

Using Two Nonlinear Methods

Frances C. James

Department of Biological Science, Florida State University,

Tallahassee, Florida 32306-2043, USA

David A. Wiedenfeld

Museum of Natural Science, Louisiana State University,

Baton Rouge, Louisiana 70803, USA

Charles E. McCulloch

Biometrics Unit, 337 Warren Hall, Cornell University,

Ithaca, New York 14853, USA

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Abstract. The analysis of continental-scale trends in bird populations is difficult. In this paper we summarize methodological problems associated with the determination of trends in data from the Breeding Bird Survey (BBS), and we illustrate applications of two methods of analysis, nonlinear nonparametric route regression (NNRR) and nonlinear semiparametric route regression (NSRR). The NSRR model allows for possible changes over time in the ability of observers to detect birds, and the results of both methods can be used to estimate the statistical significance of population trends.

With NSRR we estimate that the total number of Neotropical migrant warblers (Parulinae) declined by 6% in eastern and central North America between 1970-72 and 1986-88, but with both NNRR and NSRR the median trend among the 26 species, those for which the best data are available, was positive. We found no evidence that species breeding in woodland or forest habitats have been declining or that more species were declining than increasing in the last half of the 25-year BBS period. Differences between these results and those of the U.S. Fish and Wildlife Service, which uses linear route regression (LRR) with BBS data, must be due to differences in criteria for the selection of routes, the type of model fit for the trends, or the ways in which the data were handled.

To discover whether there is geographic variation in population trends among physiographic strata, we fit a probit-normal model incorporating random stratum effects and fixed species effects to a matrix of increases and decreases in species by strata. This analysis indicated statistically significant geographic variation. With NNRR, the average species in several strata in the southern Appalachian Mountains and the Ouachita Mountains were estimated to have a higher than 0.7 probability of a

decreasing trend. With NSRR the Adirondack Mountains as well as the Cumberland Plateau and Blue Ridge Mountains met this criterion. These results suggest that atmospheric contamination, a correlate of altitude, should be considered as an environmental factor that may be affecting long-term trends in bird populations.

The special focus in conservation biology on overall declines in Neotropical migrant land birds is not based on strong scientific evidence. However, we think that the comparative analysis of BBS data for all land birds at the level of the physiographic stratum will continue to be a useful approach.

Key words: warblers, Neotropical migrants, regression, Breeding Bird Survey, nonlinear methods, LOESS, population trends, atmospheric pollution, probit-normal model, Parulinae

Key phrases: comparisons of regression methods, population declines in highland areas

Introduction

Pressure to contribute to responsible stewardship of the biota makes researchers susceptible to the danger of codifying their concerns about environmental degradation into unwarranted generalizations about population declines, without adequate documentation and analysis. Managers add to this pressure by asking for advice, so the temptation to make generalizations is great. Nevertheless, this temptation should be resisted. The responsibility for describing the extent of uncertainty about past changes and predictions for the future falls entirely on the researcher. In the case of a topic like long-term population trends in birds, unwarranted generalizations are likely to be exaggerated further by the press, possibly creating a feedback loop.

The idea that Neotropical migrants in general and wood warblers (Parulinae) in particular have had declining populations in recent decades has become so familiar that it is often used as an assumption in both scientific and popular writing (Terborgh 1989, 1992, Ehrlich et al. 1992, Studds 1992, Line 1993). The "declines" are variously attributed to tropical deforestation, fragmentation of habitats on the breeding grounds, nest predation, cowbird parasitism, and defoliation by insects (see review by Askins et al. 1990). We think that, although these processes can be demonstrated, some authors of such articles have succumbed to the temptation mentioned above, often basing their conclusions about declines on extrapolations from the results of local studies to larger areas and even to the entire geographic ranges of the birds in question and often failing to consider alternative causes.

For some species, like the Prairie (Dendroica discolor) and Cerulean (D. caerulea) Warblers, the evidence for population declines is overwhelming, but for the majority, evidence of declines is either weak or nonexistent. Even so, if major population declines, or even regional declines, were occurring, their early detection and analysis would be important.

Only one source of data exists for assessing long-term continental-scale population trends in land birds in North America. This source is the Breeding Bird Survey (BBS), a program of standardized roadside censuses cosponsored by the U.S. Fish and Wildlife Service (FWS) and the Canadian Wildlife Service and conducted by knowledgeable volunteers. Birds seen and heard within 0.4 km are recorded at 0.8-km intervals along survey routes that are 39.4 km long. The BBS has been criticized for its bias toward the detection of singing male birds (Bart and Schoultz 1984) and for the fact that it is a roadside census that does not sample all forest and wetland habitats adequately. However, given proper attention to sources of bias, enough data, and a suitable analysis, BBS data should be able to document declines in most songbirds if they are in fact occurring (Butcher et al. 1993). Although the BBS data set is not ideal, it at least has some chance of sampling the populations of interest on a regional or continental scale, and its analysis could lead to inferences about processes that are in fact regulating broad-scale population changes. There is certainly no chance of sampling populations of amphibians, reptiles, or mammals in such a comprehensive way.

The first major summary of BBS data (Robbins et al. 1986) was based on a method of analysis called loglinear route regression (LRR, Geissler and

Noon 1981). It did not treat Neotropical migrants in particular, but it reported that from 1965 to 1979 population trends in two important groups of Neotropical migrants, wood warblers (Parulinae) and vireos (Vireonidae), were upward. A later paper (Robbins et al. 1989), which focussed on Neotropical migrants that breed in forests, reported that the high levels of increase in the 1970's did not persist into the 1980's and that in fact there had been serious declines in the 1980's. That paper has been the most important reference and authority for the justification of a large interagency program of research and monitoring in the United States (Partners in Flight) concerned with the purported decline of Neotropical migrants.

The objectives of this paper are (1) to describe two nonlinear methods of analysis of BBS data, nonlinear nonparametric route regression (NNRR) and nonlinear semiparametric route regression (NSRR), and to compare them with the method used by the FWS (linear route regression, LRR); (2) to present the results of analyses of population trends in 26 species of wood warblers (Parulinae) using NNRR and NSRR; (3)to illustrate how geographic variation in multispecies groups can be analyzed in a probabilistic way; and (4) to explain why we think that most populations of Neotropical migrant birds are not in a critical general decline.

Methods of Analysis of Population Trends

Nonlinear Nonparametric Route Regression (NNRR), Nonlinear Semiparametric Route Regression (NSRR), and Comparison with Loglinear Route Regression (LRR)

Analysis of BBS data requires many decisions. We have developed a method called nonlinear nonparametric route regression (NNRR, James et al.

1990), and here we also use a modification of it called nonlinear semiparametric route regression (NSRR). Because both are nonlinear methods, they are very flexible. They can detect changes in the direction of a population trend and changes in its rate. The FWS uses a linear method, here called linear route regression (LRR), which calculates straight lines on a log scale (Geissler and Noon 1981, Geissler and Sauer 1990, Sauer and Geissler 1990). Differences between our results and those of the FWS (Table 1) could be due to any combination of the following factors.

(1) We are more selective in choosing routes for analysis. Here we use only those routes with top-quality observers (as judged by the FWS) and with data in each quintile of years between 1966 and 1992. A species must have been recorded on more than 5% of the route years and on at least five routes for the physiographic stratum to be included in an analysis. The FWS sometimes uses more than twice as many routes, so problems with missing data and unreliable trend estimates are dealt with by a complex weighting scheme.

(2) NNRR and NSRR route analyses use LOESS, a nonlinear regression technique (Cleveland and Devlin 1988), and apply it directly to the counts of birds on survey routes (see also Taub 1990). A major advantage of this technique is that it allows comparisons of nonlinear trends among areas (James et al. 1990, 1992, in press). Tests for the overall significance of trends are z-tests for differences between sets of years. These tests use variances among routes within strata as the denominator (James et al. 1992). The FWS method (LRR) uses a mixture of ratio methods and linear methods to determine the trend for each route. The trend is quantified as

the slope of a linear regression of the natural log of the count of birds. This process transforms an assumed multiplicative relationship on the original scale to a linear additive one on the log scale. The difference of the linear regression slope from zero is used as a test criterion. LRR weights estimated trends for routes by the mean route count and the number of years of data (Geissler and Sauer 1990). The FWS also claims to weight routes for precision, but doing so is not possible without estimating within- and between-route variances, which they do not do.

(3) To agglomerate trend estimates to successively larger areas, NNRR and NSRR weight them by the proportional sizes of the areas, as does LRR, except that the first level of agglomeration for LRR is stratum within state; for NNRR and NSRR it is stratum. If a species occurs in only one part of a stratum, we reduce the weight of that stratum accordingly.

(4) When we compare early and recent periods in the data, we use the same set of routes for the comparison. The FWS adds newly established routes to their late-period analyses. Many new routes that have been added to the BBS program since the early years have not had randomly selected starting points, as did the original set of routes.

Peterjohn et al. (in press) think new observers who have taken over BBS routes are more adept in their ability to detect birds than were those whom they replaced. If this were true, it would introduce a positive bias into any trend analysis. Of course, if aging observers were gradually losing their hearing ability, that would introduce a negative bias. LRR uses the observer as a covariable (Faanes and Bystrak 1981, Geissler and Noon 1981). NSRR is a modification of NNRR that can fit smooth relationships of population size through time while incorporating observer effects. This semiparametric model, described by Hastie and Tibrishani (1990), is still flexible, but adding this step involves a tradeoff. Estimates based on NSRR for years when a route was not run are less reliable than are estimates with NNRR, especially at the beginning and end of the BBS period. Because we found that the most stable estimates of overall trends were obtained by comparisons of periods that were four years from the ends of the full period, the overall estimates reported here are for the 16-year period between 1970-72 and 1986-88. Of course estimates for terminal years are less reliable, no matter what method is used, and this effect is exaggerated when observer covariables are in the model. Here we report the results of NSRR for all routes that converged on a solution within 300 iterations. So that the reader can evaluate the tradeoff between the two models, we report the results of analyses based on both NNRR and NSRR. The analysis of trends in BBS data is a very complex issue, one in which more work is needed.

Methods for Making Multispecies Comparisons

When we make comparisons across species, we do not assume that the species can be treated as independent observations. Because the data are often from the same locations, that is an invalid assumption, but it is used in many FWS tests. Application of a probit-normal model avoids these difficulties and is described below.

To discover whether there has been geographic variation in population trends, we created a table of the 26 species by the 38 strata and filled the cells with 1's and -1's for estimated increases and decreases for each species for the period between 1970-72 and 1986-88. We fit a probit-normal model incorporating random stratum effects and fixed species effects

(McCulloch in press). We then estimated the best predicted values of the stratum effects. If there were no geographic differences in population trends among strata, all the stratum effects would be zero, and a hypothetical average species would have, for each stratum, a probability of decrease equal to the overall probability of decrease across strata. In the presence of stratum effects, favorable strata will have a low probability that an average species will decrease, and unfavorable strata will have a high probability of decrease. These estimated high probabilities of decrease for a hypothetical, average species have two major advantages over the observed proportions of declining species. First, they account for differences in species composition in different strata. Thus, a stratum is not declared unfavorable merely because it contains a collection of species that are declining uniformly across strata. Second, it accounts for differences in sample sizes and assigns less weight to strata with few species.

Results

Population Trends in Warblers

Using both NNRR and NSRR on data for 922 routes (Fig. 1), we give the average number of birds per route for 1986-1988 and percent changes since 1970-72 for the 26 most common species of warblers that breed in the eastern and central U.S. and Canada (Table 1), arranged in order of their estimated population trends (percent change) as estimated by NNRR. The median trend (middle value for percent change among the 26 species) is an increase of 16% with NNRR and 2% with NSRR. With NNRR, four species are estimated to have had statistically significant negative population trends in the area studied here; with NSRR, six species had significant negative trends. The four species with the most severe declines are the Cerulean, Prairie, and Canada Warblers, and the Yellow-breasted Chat. At the other end of the list, the species with the highest statistically significant estimated increases with NNRR are the Blue-winged, Mourning, Black-throated Blue, Blackburnian, and Magnolia Warblers and the Northern Parula. Whether the NSRR results for the Black-throated Blue and Blackburnian Warblers and the Northern Parula are more reliable than those for NNRR is unknown.

When NSRR is used separately on data for the first and last halves of the BBS period, we do not see a higher percentage of declining species in the more recent period (Table 2). Also, for the 16 species in our sample that can be compared directly with recent analyses by the FWS (Peterjohn et al. in press) (because the breeding ranges of these species are within the area we used), the median trend using NSRR is an 11% increase, and with LRR it is a 2% increase (Table 2). We found no evidence that warblers that breed in forested habitats are doing less well than those in open, successional, and scrub habitats (Table 1).

Geographic Variation in Population Trends

A histogram in which the strata are arranged in decreasing order of their numbers of species of warblers and that shows the number of species estimated to have declined in the BBS period (Fig. 2) allows visual identification of strata that seem to have unusual proportions of increasing or decreasing species (Table 3).

The application of the probit-normal model to the matrix of increases and decreases by species and strata indicated that indeed there is statistically significant overall geographic variation in population trends. In a particularly poor stratum, that is, one with a high proportion of declining species, like the Cumberland Plateau, the probability of decrease based on NNRR changed from 0.50 to 0.76; in a particularly good one, that is, one with a low proportion of declining species, like the St. Lawrence River Plain, the probability of decrease changed from 0.50 to 0.20 (Table 4).

With NNRR, the probability of decline for an average species was greater than 0.7 in four strata in the Southern Appalachians and in the Ouachita Mountains (Table 4a, Fig. 3). With NSRR, the Adirondack Mountains, as well as the Cumberland Plateau and Blue Ridge Mountains, met this criterion (Table 4a, Fig. 4).

The most significantly declining and increasing species (Table 1) showed exceptional trends in the highland strata. For example, with NSRR the stratum with the largest decline in Canada Warblers was the Adirondack Mountains; the one with the largest decreases in Cerulean and Prairie Warblers was the Cumberland Plateau; the one with the largest percent decline in the Prairie Warbler was the Blue Ridge Mountains; and the one with the largest percent decline in the Cerulean Warbler was the Ouachita Mountains. The Mourning Warbler increased in all strata except the Adirondacks; the Magnolia Warbler, which was also significantly increasing overall, had its highest increase in the Adirondacks. These estimates suggest that dynamic changes have been taking place in breeding bird populations in highland areas.

With NNRR, the probability of decline for an average species was less than 0.3 in an area from New England and the southern sections of the maritime provinces of Canada westward through the Great Lakes Plain and prairie provinces of Canada (Table 4b, Fig. 3). With NSRR only the St.

Lawrence River Plain met this criterion (Table 4b, Fig. 4). This result means that the chance that the average species will have increased in numbers in that strata is greater than 0.7.

All Species Combined

We examined summary values for the numbers of individual warblers of all species combined and their changes among strata between 1970-72 and 1986-88 (Table 3). Early in the BBS period, observers in the Cumberland Plateau and the Adirondack Mountains recorded the highest numbers of warblers (an average of more that 100 warblers per route). By the late 1980's the highest numbers were recorded in the spruce hardwoods and boreal forests of Canada (an average of 90 warblers per route), as opposed to about 70 for the Cumberland Plateau and Adirondack Mountains and about 35 for the Blue Ridge Mountains. The overall average of individual warblers per route in 1986-88 was 18, a statistically significant decline of 6% since 1970-72 spread over 22 of 37 physiographic strata (Ozark Plateau and Ouachita Mountains were combined). The extent to which this decline is dominated by declines in highland strata or in species that are widespread and still numerous, like the Common Yellowthroat, will require further study, as will the biological interpretation of the overall result.

Analysis by the Number of Stops on Which a Species Was Recorded

Observers may be more variable in their counts of the number of individuals at a particular stop along a BBS route than they are in their detection of the presence of a species at a particular stop. We used NNRR to estimate the percentage of species declining, on the basis of the number of stops at which each species was recorded. The results were identical or very similar to the values in Table 3 for individuals per route:

Adirondack Mountains, 53%; Cumberland Plateau, 72%; Blue Ridge Mountains, 82%; Ouachita Mountains, 73%; Southern Piedmont, 85%; Ozark Plateau, 56%.

Discussion

Lack of Evidence of Serious Declines in Neotropical Migrant Birds as a Group

The most recent summary of BBS data from the FWS, which is for 1966-1991 (Peterjohn et al. in press; see Table 2, lower part), reports that the percentage of declining species of Neotropical migrants, including warblers, was higher in the recent half of the BBS period than in the earlier half, as did Robbins et al. (1989). However, the estimated percentage of Neotropical migrants declining was 30% in the first half of the period and 54% in the second half; for warblers, the percentage declining was 22% in the first half of the period and 56% in the second half. Thus, with the FWS analysis, it is the high proportion of increasing populations before 1979 (70% of all Neotropical migrants and 78% of all warblers increasing) rather than the high proportion declining since 1979 that seems to demand explanation. If nothing unusual were going on, one would expect about 50% increasing and 50% decreasing species, so without additional analysis, estimates of 54% of Neotropical migrants and 56% of all warblers decreasing in the recent period are not alarmingly high values. Furthermore, in addition to the problems with lack of independence mentioned in the section on methods for making multispecies comparisons, a serious question with respect to the FWS analysis of separate time periods is how the break at 1979 was decided upon. Significance tests based on data-driven hypotheses can be misleading. Although we have not repeated the FWS analyses, we do not see that they support the idea that Neotropical migrant birds as a group have been in a serious decline.

Independent analyses by the Canadian Wildlife Service based on a modification of LRR have indicated more significant increases than decreases in Neotropical migrants in Canada (Erskine et al., 1992). Adams et al. (1998) report generally increasing trends in Neotropical migrants in Michigan.

Methodological Issues

Here we examined data for only 26 species of warblers in eastern and central North America, but they are the 26 for which the most data are available and the chance of obtaining reliable estimates is best. It is interesting that the median trend for all 26 species of warblers is lower with NSRR (2%) than with NNRR (16%). This difference may be due to an observer effect, but the tradeoff in precision involved with adding observer effects to the model would necessitate more analysis to establish this relationship. We do not know why we do not see the same differences between early and recent periods in the percentages of species declining that have been reported by the FWS. Another question is why the identification of the Canada Warbler as a species in serious decline both in our analyses and in that of the Canadian Wildlife Service (Erskine et al. 1992) was not detected by the FWS (Sauer and Droege 1992, Peterjohn et al. in press). The answers are somewhere in the many differences in how the routes were selected and the data were handled.

Nonparametric regression methods (such as NNRR and NSRR) estimate a regression curve without making strong assumptions about the shape of the true regression function (Altman 1992). The methods are used here to estimate population trends in terms of counts of birds per route (or stops on a route on which a species was recorded) for routes on which the species occurred. LOESS estimates of three-year averages (1970-72, 1986-88) were determined from all the data, not just data for those years, and t-tests were used for testing the significance of population trends within strata; z-tests were used for testing the significance of trends by species. We illustrate the advantages of the flexibility of nonlinear methods elsewhere (James et al. 1990, 1992). Nonparametric tests can also be appropriate for testing the statistical significance of trends in environmental data (Thomas et al. 1978, Hirsch et al. 1982, Berryman et al. 1988). We do not agree with the FWS (Peterjohn et al. in press) that the most reliable way to determine the statistical significance of a population trend in BBS data is to test whether the slope of a linear regression is different from zero.

Geographic Variation

Our initial work with BBS data for warblers used graphs to compare nonlinear population trends in the resident Pine Warbler, *Dendroica pinus* (James et al. 1990), and in the eight most common species of Neotropical migrants in the southeastern United States (James et al. 1992). Although there was no overall decline in the eight Neotropical migrant species as a set, populations of most of them were doing less well in the highland areas of the combined Ozark Plateau and Ouachita Mountains, the Ridge and Valley, Cumberland Plateau, and Blue Ridge Mountains than in the coastal plain and piedmont areas. That result is extended by the results reported here to include all 26 species of warblers in eastern and central North America for which we think that reliable estimates can be made. In addition to the estimates of unusual declines in highland areas in the southern

Appalachians, NSRR has indicated that unusual declines have occurred in warblers in the Adirondack Mountains. No published analyses of BBS data have indicated generally declining bird populations west of the Great Plains, but clearly the issue of possible altitudinal effects should be checked there.

Our conclusion, that altitude may be a correlate of declines in warblers in eastern and central North America, is based on data from some strata that have only a few routes that met our selection criteria (Table 3), so it must be considered to be tentative. However, last year we used NNRR to estimate population trends for 65 species including Neotropical migrants, partially Neotropical migrants, temperate zone migrants, and resident species (unpublished report by Wiedenfeld et al.). Although no group was found to be in decline, that report identified three of the Appalachian strata mentioned above (Adirondack Mountains, Cumberland Plateau, and Blue Ridge Mountains) as areas with high proportions of declining species. Thus these declines are probably not just a property of warblers or of Neotropical migrants, but of all groups of breeding land birds.

Analysis of Causes

The results reported here suggest that atmospheric pollution, a correlate of altitude, may affect North American bird populations. Graveland (1990) reviews research in Europe on the relationship between atmospheric pollution and bird populations, including experimental confirmation of causal effects. Similar work would be required to establish a causal relationship in the United States. Atmospheric pollution can affect the growth of trees directly and can indirectly affect caterpillar and other arthropod populations, the main food of songbirds in the summer. Also, atmospheric pollution can reduce the availability of minerals such as calcium in the vegetation and soil, and female songbirds need extra calcium at the time of egg-laying.

The most common causes proposed to account for purported declines in Neotropical migrants, all of which have been invoked for warblers, are, first, deforestation in the tropics (Robbins et al. 1989); second, forest fragmentation (Robinson 1992), cowbird parasitism (Robinson 1992), predation (Bohning-Gaese et al. 1992, Martin 1992), and drought (Blake et al. 1992) in the breeding grounds; and, third, processes occurring during the vagaries of migration (Gauthreaux 1992). Such potentially limiting environmental forces can all be demonstrated in parts of the geographic ranges of the species in question. The more important question is the extent to which such environmental factors are in fact limiting the numbers of birds. Even factors that can be shown to cause high mortality are not necessarily those that ultimately determine population levels (Newton 1991). None of the causes listed above has been invoked to account for the population peaks of Neotropical migrants in 1980 reported by the FWS, so analyses of causes of population trends in Neotropical migrants have not been progressing well.

Elsewhere we illustrate ways to use graphs to study geographic variation in nonlinear population trends (James et al. 1990, 1992), and we explore the possibility of analyzing causes of trends by making comparisons based on quasiexperimental designs (James et al. in press). See also Bohning-Gaese et al. (1992) for an analysis based on BBS data that explores causes. Clearly, the sorting out of potential causes should involve analytical sampling (Eberhardt and Thomas 1991). Ideally, studies should combine censuses in areas that have different levels of environmental factors with data on reproductive success and survival of marked birds in these areas.

Summary and Recommendations

1. Here we used nonlinear nonparametric route regression (NNRR) and nonlinear semiparametric route regression (NSRR) for the analysis of BBS data. These methods are flexible and involve minimal assumptions about the form of the curve of population size through time. The results can be used to test the statistical significance of population trends, and NSRR allows observer covariables to be included in the model.

2. Our analyses for the period 1966 to 1992 indicate that, although the total number of individual warblers has declined by an estimated 6%, only a few of the 26 most common species of warblers have had seriously declining populations. The overall proportion of species with decreasing trends is not higher than that with increasing trends, nor do we see a change toward decreasing trends of warblers between the first and second halves of the BBS period, as reported by the FWS. The reasons must involve differences in our choice of routes for analysis and how the data were treated. Nevertheless, we think our methods are reasonable, and we are forced to conclude that the special concern in the last decade about the conservation of Neotropical migrant warblers as a group, at the expense of attention to population trends in other birds, has been unwarranted.

3. In spite of the fact that warblers as a group do not show alarming declines in the eastern and central regions of North America, we estimate that some species have had declining populations in highland areas. Also,

those species with the most seriously declining populations overall had their extreme decreases in these areas. We think research that compares the breeding biology of all birds in these physiographic strata with populations of the same species in other environments is called for. We are reminded of the excellent studies in Europe that first linked trends in bird populations with atmospheric pollution, a correlate of altitude. This finding was later supported with experimental evidence.

4. One way to facilitate progress with studies of North American land-bird populations would seem to be to enlarge the issue from emphasis on Neotropical migrants to study of all species for which BBS data are appropriate and to emphasize more detailed study of geographic variation in nonlinear population trends. Comparisons of rates of reproduction and survival of marked birds, like those of Sherry and Holmes (1993), in areas with different trends and different environmental conditions will be required before the causes of declines can be established.

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Table 1. Estimates of population trends in 26 species of warblers from 1970-72 to 1986-88, based on analysis of data for 923 Breeding Bird Survey routes in eastern and central North America north of Mexico, using nonlinear nonparametric route regression (NNRR) and nonlinear semiparametric route regression (NSRR). Results from the U.S. Fish and Wildlife Service (Peterjohn et al. in press) for the 16 species with geographic ranges entirely within this area are given for comparison. The latter are based on loglinear route regression (LRR).

	No. routes	No. strata	Birds/route 1986-1988		% Change from 1970-72 to 1986-88		% Change from 1970-72 to 1986-88[b]
	NSRR[a]	NSRR[a]	NNRR	NSRR	NNRR	NSRR	LRR
1. Cerulean Warbler[W]	95	8	0.2	0.1	-47*	-71*	-53*
2. Prairie Warbler[S]	320	16	0.8	0.8	-41*	-45*	-46*
3. Canada Warbler[W]	144	6	0.7	0.6	-37*	-50*	7
4. Yellow-breasted Chat[S]	406	21	2.8	3.0	-27*	-24*	
5. Golden-winged Warbler[S]	105	8	0.2	0.2	-27	-39	-46*
6. American Redstart[W]	429	21	1.2	1.1	-10	-32*	
7. Prothonotary Warbler[W]	189	10	0.4	0.4	- 4	-19	- 8
8. Northern Waterthrush[W]	146	7	0.5	0.5	0	11	

Table 1 (continued).

	No. routes NSRR[a]	No. strata NSRR[a]	Birds/route 1986-1988 NNRR	Birds/route 1986-1988 NSRR	% Change from 1970-72 to 1986-88 NNRR	% Change from 1970-72 to 1986-88 NSRR	% Change from 1970-72 to 1986-88[b] LRR
9. Chestnut-sided Warbler[s]	251	12	3.3	3.1	2	4	-10
10. Nashville Warbler[s]	158	7	3.0	2.8	3	0	31
11. Common Yellowthroat[s]	747	36	7.5	7.1	4	- 9*	
12. Kentucky Warbler[w]	277	15	0.8	0.9	14	12	-12
13. Louisiana Waterthrush[w]	268	14	0.1	0.2	16	107*	2
14. Black-throated Green Warbler[w]	190	10	1.4	1.0	16	-15	- 2
15. Worm-eating Warbler[w]	156	10	0.1	0.1	16	-24	10
16. Yellow-throated Warbler[w]	202	13	0.3	0.3	24	6	7
17. Yellow Warbler[s]	612	30	2.6	2.5	26*	12	
18. Black and White Warbler[w]	387	19	0.9	0.7	27*	-19	
19. Ovenbird[w]	442	20	5.3	4.5	29*	18*	

Table 1 (continued).

	No. routes	No. strata	Birds/route 1986-1988		% Change from 1970-72 to 1986-88		% Change from 1970-72 to 1986-88[b]
	NSRR[a]	NSRR[a]	NNRR	NSRR	NNRR	NSRR	LRR
20. Hooded Warbler[w]	213	13	0.2	0.8	30	8	2
21. Northern Parula[w]	320	19	0.9	0.8	34*	17	17
22. Magnolia Warbler[w]	150	6	2.7	2.4	35*	41*	
23. Blackburnian Warbler[w]	153	7	0.7	0.6	36*	11	17
24. Black-throated Blue Warbler[w]	128	7	0.4	0.2	46*	- 9	7
25. Mourning Warbler[s]	157	7	1.7	1.7	51*	102*	
26. Blue-winged Warbler[s]	208	12	0.2	0.2	61*	38	
Median % change					+16%	+ 2%	
Nesting in woodland or forest					+20%	+12%	
Nesting in open, successional, or scrub habitat					+ 3%	+ 3%	
Median % change (16 species)						+11%	+2%

Table 1 (continued).

[a]Numbers for NNRR are the same or slightly higher.

[b]Calculated by raising percent change per year to the power of the number of years difference. LRR analyses are based on analyses that used approximately twice as many routes as NNRR and NSRR analyses.

[w]Nesting in woodland or forest.

[s]Nesting in open, successional, or scrub habitat.

Table 2. Comparison of early, recent, and overall trends in Neotropical migrants and in warblers alone using nonlinear semiparametric route regression (NSRR) and linear route regression (LRR) analyses of data from the Breeding Bird Survey. The NSRR analysis is for eastern and central North America north of Mexico. The LRR values are summarized from the most recent continent-wide analysis by the U.S. Fish and Wildlife Service (Peterjohn et al. in press).

	Number of	% of species declining		
	species	Early	Recent[a]	Overall
Nonlinear Semiparametric Route Regression (NSRR) 1966-1992				
Warblers[b]	26	46	42	46
Warblers (same geographic area as below)	16	56	44	50
Loglinear Route Regression (LRR) 1966-1991				
Neotropical migrants[c]	97	30	54	45
Warblers[c]	41	22	56	34
Warblers (reported above, but for a larger geographic area)	26	27	58	42
Warblers (same geographic area as above)	16	37	56	44

Table 2 (continued).

[a]Early and recent periods for NSRR are 1970-72 to 1978-80 and 1978-80 to 1986-88; for NRR they are 1966 to 1979 and 1979 to 1991. The estimates with NSRR are based on regressions that use all data from 1966 to 1992.

[b]Based on all species with at least 95 routes.

[c]Based on all species for which the number of routes minus the number of state-stratum units is at least 15.

Table 3. Average number of individual warblers per BBS route in 1986-88, estimated with NSRR from data for a total of 922 routes in 37 physiographic strata, and percent change since 1970-72[a], average number of species per BBS route in 1986-88 and percent declining since 1970-72.

	No. of routes	Species/ route 1986-88	% declining since 1970-72	Individual warblers/ route 1986-88	% change since 1970-72[b]
Eastern Coastal Plain and Mississippi Embayment					
1. Floridian	9	3	67	10	3
2. Coastal Flatwoods	23	8	25	21	-2
3. Coastal Prairies	10	2	0	3	81
4. Mississippi Alluvial Plain	13	9	67	14	-45
5. Eastern Texas Prairies	16	1	0	<1	>100
6. S. Upper Coastal Plain	69	14	43	23	-9
7. N. Upper Coastal Plain	32	13	54	27	-5

Table 3 (continued).

	No. of routes	Species/ route 1986-88	% declining since 1970-72	Individual warblers/ route 1986-88	% change since 1970-72[b]
Eastern Foothills and Central Highlands					
8. Southern Piedmont	17	13	54	24	-15
9. Northern Piedmont	24	14	36	15	29
10. Highland Rim	36	16	50	32	-15
11. Lexington Plain	11	11	55	32	-21
12. Ridge and Valley	44	19	58	23	-18
13. Ozark Plateau and Ouachita Mountains (combined)	22			20	-11
13a. Ozark Plateau	(16)	16	50		
13b. Ouachita Mountains	(6)	15	67		
14. Southern New England and Glaciated Coastal Plain	25	17	29	50	5

Table 3 (continued).

	No. of routes	Species/ route 1986-88	% declining since 1970-72	Individual warblers/ route 1986-88	% change since 1970-72[b]
Appalachian Mountains					
15. Blue Ridge Mountains	4	16	75	37	-49
16. Cumberland Plateau	6	18	85	69	-43*
17. Ohio Hills	21	15	47	41	-18
18. Allegheny Plateau	45	24	33	50	20*
19. Adirondack Mountains	8	15	80	74	-28*
20. Northern New England	22	17	59	70	-4
Spruce-Hardwoods and Boreal Forest					
21. Spruce-Hardwoods and Boreal Forest	86	16	38	90	1
Great Lakes Plains					
22. St. Lawrence River Plain	24	15	13	26	42*
23. Great Lakes Plain	47	8	25	19	53*
24. Driftless Area	21	6	17	17	19

Table 3 (continued).

	No. of routes	Species/ route 1986-88	% declining since 1970-72	Individual warblers/ route 1986-88	% change since 1970-72[b]
25. Great Lakes Transition	22	12	67	45	2
Tallgrass Prairie					
26. Till Plains	45	3	33	7	1
27. Dissected Till Plains	46	4	75	10	-9
28. Black Prairie	22	2	100	13	-24
Aspen Parklands					
29. Aspen Parklands	23	7	43	16	-7
Great Plains					
30. Drift Prairie	18	2	100	17	-3
31. Glaciated Missouri Plateau	9	2	50	3	-9
32. Great Plains Roughlands	18	3	67	4	-24
33. High Plains	11	2	100	<1	-80
34. High Plains Border	29	2	0	2	>100*

Table 3 (continued).

	No. of routes	Species/ route 1986-88	% declining since 1970-72	Individual warblers/ route 1986-88	% change since 1970-72[b]
35. Rolling Red Prairies	11	1	0	<1	29
36. Osage Plain-Cross Timbers	24	7	71	2	-25
37. Edwards Plateau	9	1	0	<1	>100
Overall Average				18	-6*

[a]Ozark Plateau and Ouachita Mountains are combined.

[b]Significant values are marked by asterisks. Significance levels at a = <0.05 based on t-tests for strata, a z-test for overall average percent change.

Table 4. Physiographic strata where the estimated probability of a decline in a hypothetical species between 1970-72 and 1986-88 was higher than 0.7 (a) or lower than 0.3 (b) based on a probit-normal model applied to a matrix of increases and decreases for each species estimated by either NNRR or NSRR. Strata with high values have estimated unusual decreases, those with low values have unusual increases. If there were no geographic variation, all strata would have probabilities equal to the overall average.

	Estimated probability of decline for an average species, NSRR	Estimated probability of decline for an average species, NNRR
a. Strata with decreasing populations		
Adirondack Mountains	.75	.61
Cumberland Plateau	.76	.76
Blue Ridge Mountains	.70	.78
Ouachita Mountains	.65	.72
Ridge and Valley	.60	.71
Southern Piedmont	.55	.82
b. Strata with increasing populations		
St. Lawrence River Plain	.24	.20
Great Lakes Plain	.40	.19
Spruce Hardwoods and Boreal Forest	.41	.25
Aspen Parklands	.49	.22

[a]A high probability of decrease (>0.7) is shown in black and a low probability of decrease (<0.3) by vertical lines in Figs. 2 and 3.

Figure Legends

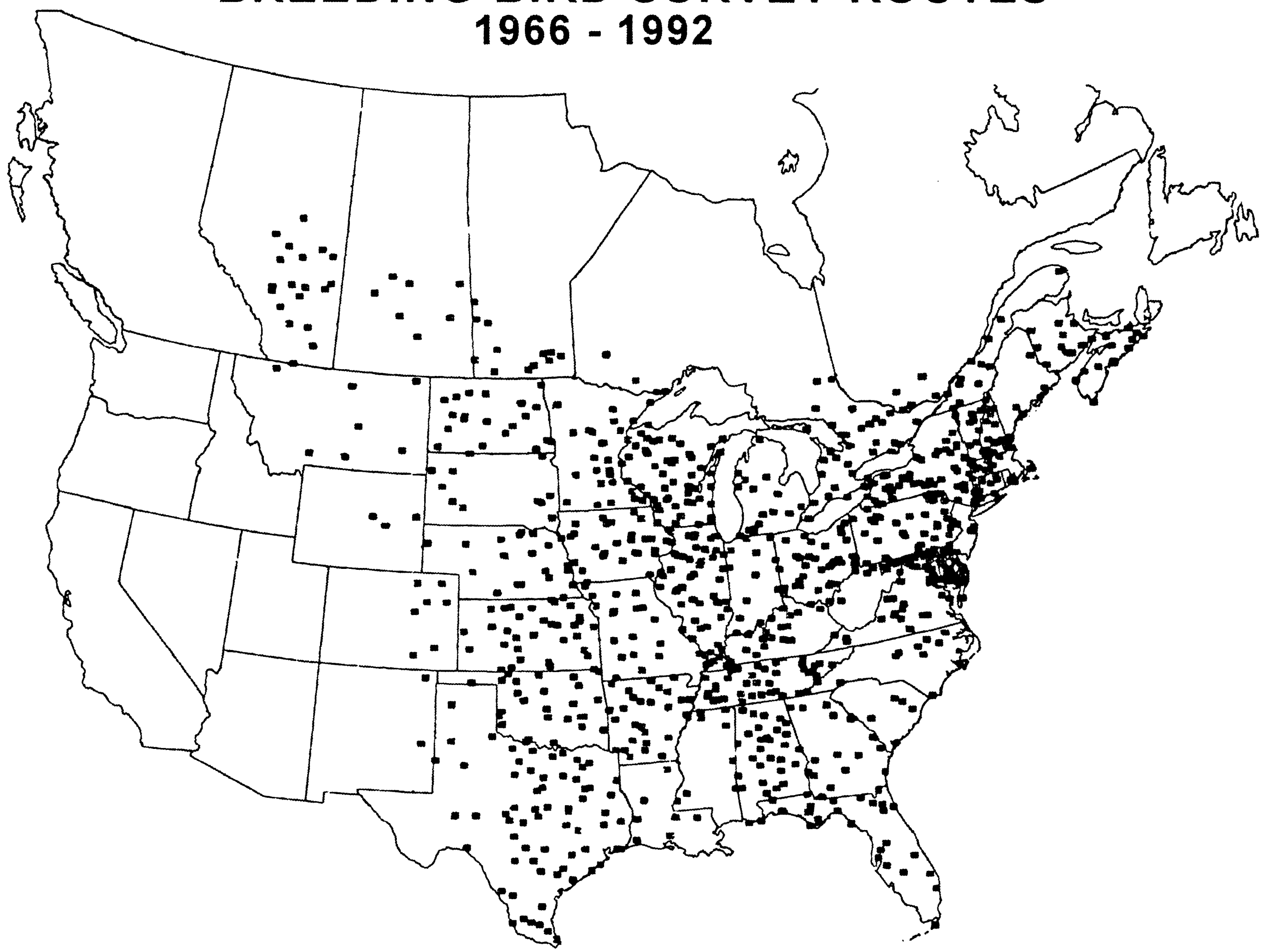
Fig. 1. The locations of 923 Breeding Bird Survey routes with data in each quintile of years from 1962 to 1992.

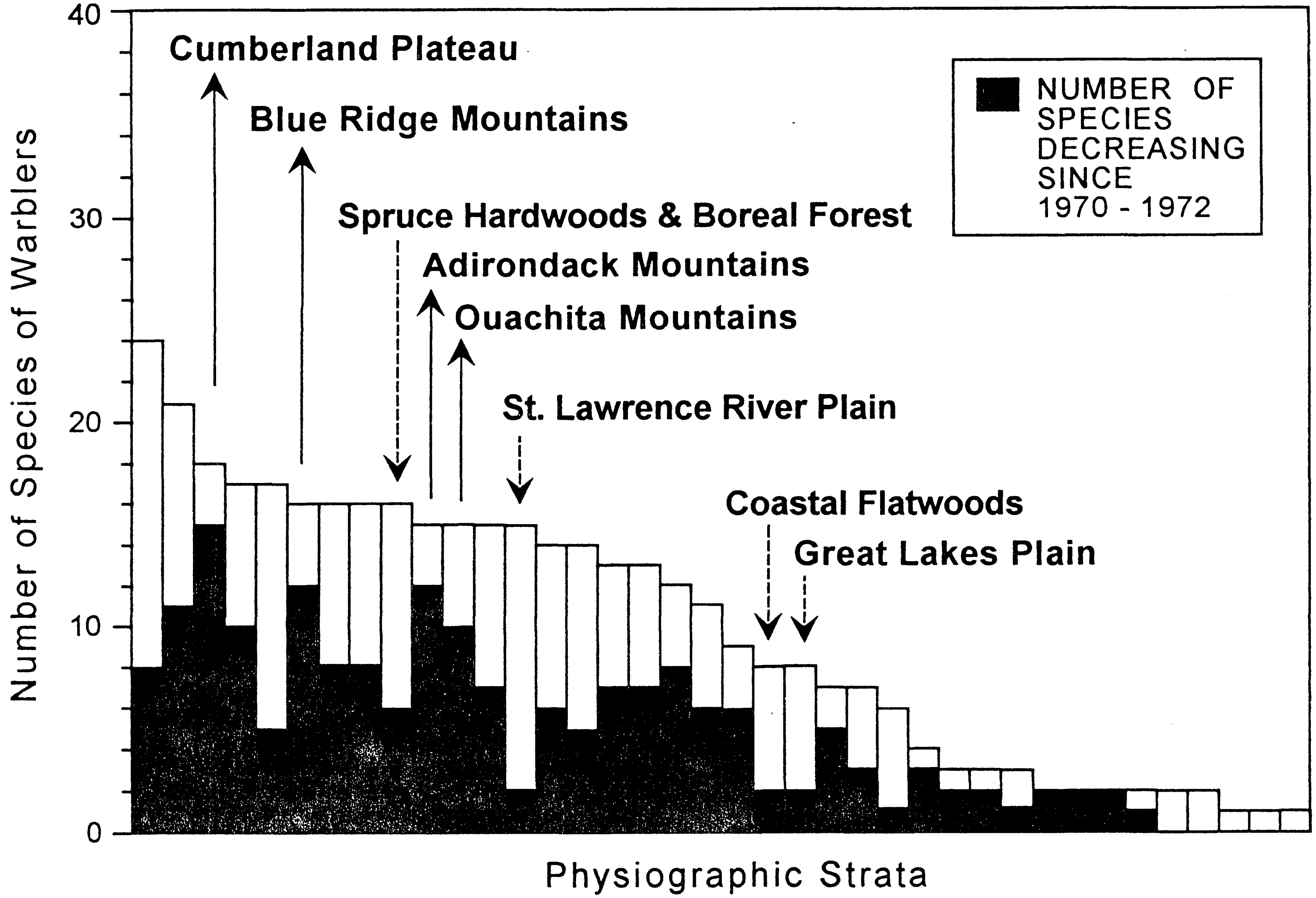
Fig. 2. Histogram of the average number of species of warblers recorded on BBS routes in 1986-88 in 38 physiographic strata in eastern and central North America, showing in black the number estimated with NSRR to have declined since 1970-72. Visual comparisons between the two variables indicate strata that seem to have unusual proportions of increasing or decreasing species. See also Table 4.

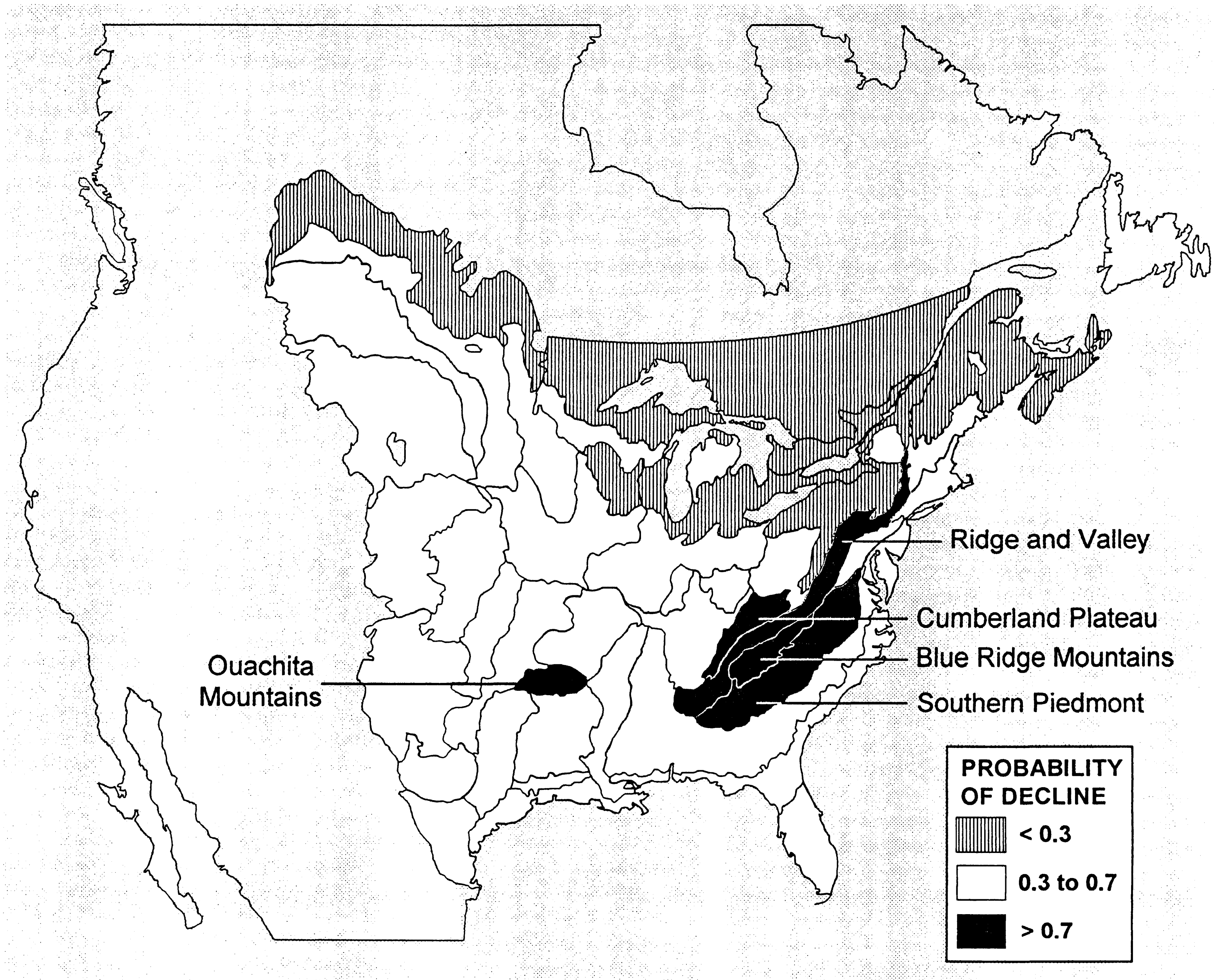
Fig. 3. The probability that an average species will be decreasing, as calculated with a probit-normal model applied to a matrix of increases and decreases for each of 26 species in 38 physiographic strata. The increases and decreases were estimated with nonlinear nonparametric route regression (NNRR). A low probability of decrease is equivalent to a high probability of increase. The strata are identified in Table 4 (two strata adjacent to stratum 37, the Edwards Plateau, had insufficient data for analysis).

Fig. 4. The probability that an average species will be decreasing, as calculated with a probit-normal model applied to a matrix of increases and decreases for each of 26 species in 38 physiographic strata. The increases and decreases were estimated with nonlinear semiparametric route regression (NSRR). A low probability of decrease is equivalent to a high probability of increase. The strata are identified in Table 3.

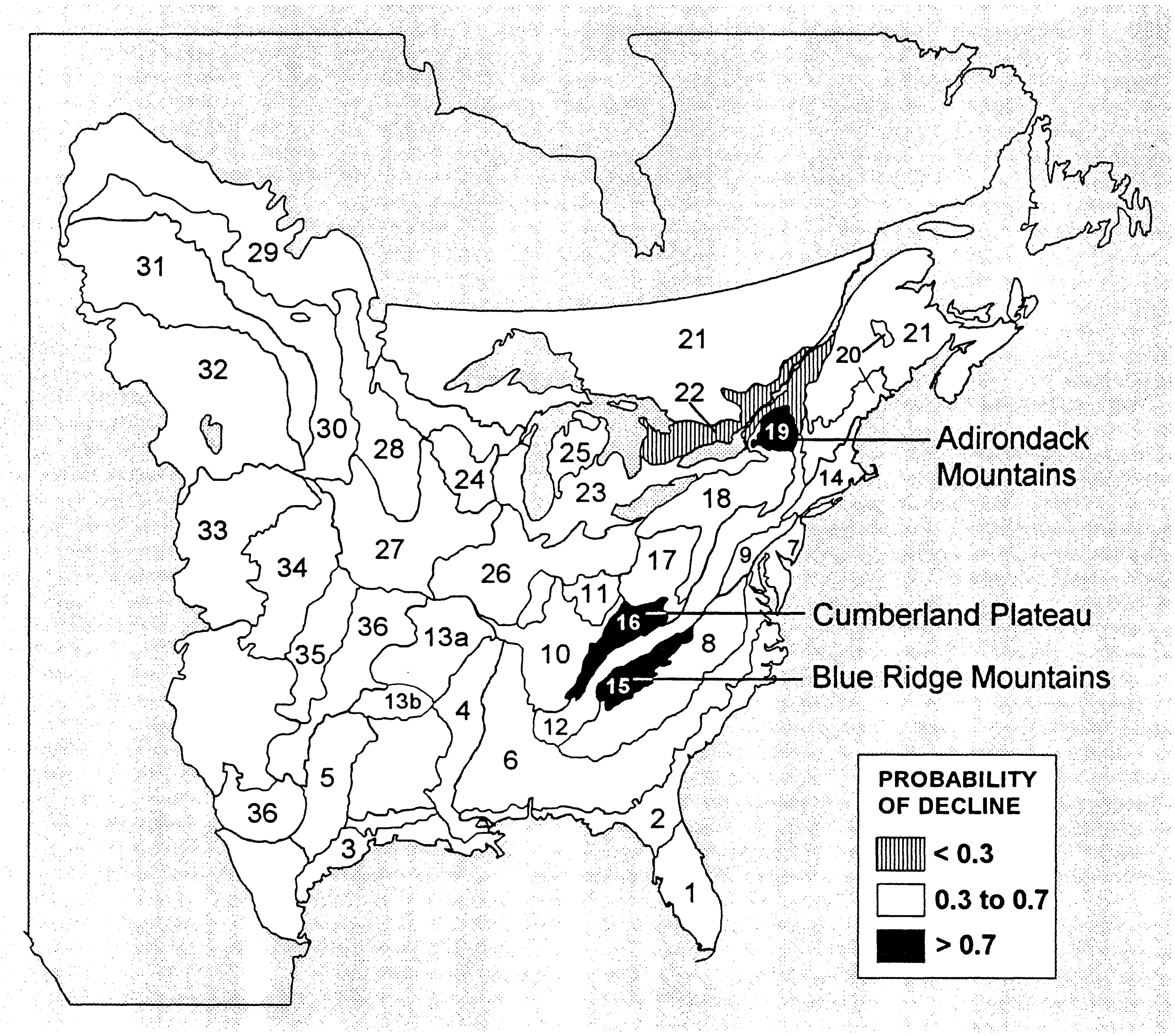
BREEDING BIRD SURVEY ROUTES
1966 - 1992




Cumberland Plateau
Blue Ridge Mountains
Spruce Hardwoods & Boreal Forest
Adirondack Mountains
Ouachita Mountains
St. Lawrence River Plain
Coastal Flatwoods
Great Lakes Plain
NUMBER OF SPECIES DECREASING SINCE 1970 - 1972
Number of Species of Warblers
40
30
20
10
0
Physiographic Strata



Ridge and Valley
Cumberland Plateau
Blue Ridge Mountains
Southern Piedmont
Ouachita Mountains
PROBABILITY OF DECLINE
< 0.3
0.3 to 0.7
> 0.7



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Adirondack Mountains
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17
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7
11
16
Cumberland Plateau
36
13a
35
10
8
15
Blue Ridge Mountains
13b
4
12
6
5
36
2
3
1
PROBABILITY OF DECLINE
< 0.3
0.3 to 0.7
> 0.7